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Development of Gas Microstrip Detectors for Digital X-Ray Imaging and Radiation Dosimetry

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Abstract - *Our recent work in the application of gas microstrip detector (GMD) technology to the fields of digital x-ray imaging and radiation dosimetry is described. The GMD can measure the position and the energy of individual photons at the high counting rates encountered in x-ray imaging. GMD based imaging systems have high detective quantum efficiency and permit improvement of image quality and contrast using display windowing and measured energy information. Results are presented on the performance of a prototype GMD imaging system operated with a xenon/methane 90/10 gas mixture at 1 atmosphere. Results are also presented on the performance of a GMD filled with tissue equivalent gases for applications in the field of radiation dosimetry in mixed neutron and γ fields. The results show that the GMD can be used for dosimetric discrimination between different types of radiation in mixed field environments.*

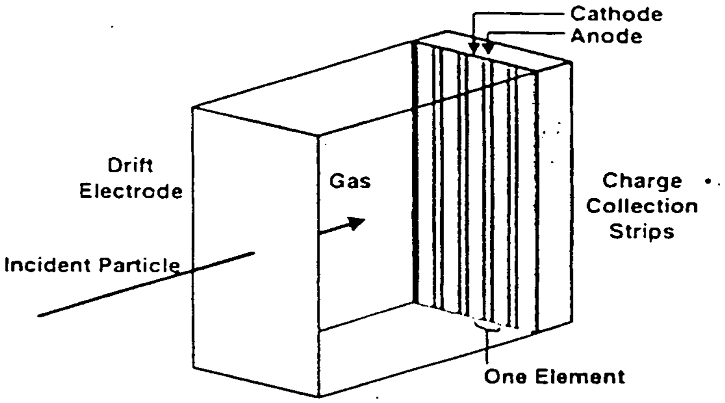

Fig. 1: Schematic diagram of a gas microstrip detector

I. INTRODUCTION

The Gas Microstrip Detector (GMD) is a recent development from experimental particle physics[1]. In essence it is a miniature multiwire proportional counter printed onto a thin rigid substrate by photolithography (Fig. 1). When a radiation interaction occurs within the detector volume, the ionization electrons are attracted toward the anodes. The strong electric field region near the anodes produces a large proportional multiplication in the number of electrons. The resulting charge Q collected on the anodes is

$$Q = M\frac{E_{ab}}{W} \quad (1)$$

where E_{ab} is the energy absorbed by the detector, W is the mean energy needed to create an electron-ion pair in the gas and M is the gas multiplication, typically between 100 and 1000 for our applications.

The very fine scale of the GMD (typical anode to anode spacing 200 μm) provides high spatial resolution. The proximity of the cathodes to the anodes results in fast clearing of the positive ions away from the gas multiplication region and permits the device to operate efficiently at counting rates in excess of $10^6\ \mathrm{s}^{-1}\mathrm{mm}^{-2}$.

For x-ray imaging, the GMD has several advantages over energy integrating devices such as film screen systems or the CCD. A GMD could be the first detector fast enough to count individual photons at radiological counting rates and to measure their energy with good resolution. For the same quantum efficiency, a photon counting GMD imaging system produces images with higher signal to noise ratio (because of its higher detective quantum efficiency) than an energy-integrating detector. Further, a digital x-ray imaging sytem incorporating a GMD would allow image quality and contrast to be enhanced using the measured energy information and display windowing. Examples of possible applications include medical

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projection radiography, CT scanning and industrial non-destructive testing.

The high spatial resolution of the GMD can also be useful in radiation dosimetry. Neutron dosimetry in the presence of the intense γ ray background in nuclear power plants presents a number of problems. The dosimetric devices must be able to measure both the dose and its weighting or quality factor (for biological damage) which depends on the radiation type through the stopping power of associated secondary charged particles. The quality factor is 1 for photons but may be as high as 20 for neutrons. In the past, tissue equivalent proportional counters (TEPC) [2] constructed of tissue equivalent (TE) material and filled with TE gas have been used for the purpose. We are investigating the possible use of the GMD operating in a manner similar to a TEPC. Potential improvements offered by the GMD include range discrimination due to the multichannel geometry and a better estimate of the dose equivalent of low energy neutrons.

II. X-RAY IMAGING

A. *Methods*

We have built a prototype scanned projection radiography (SPR) system (Fig. 2) to demonstrate the capabilities of a GMD based x-ray imaging device. The object being imaged is scanned line by line through a thin fan beam of x rays in steps of 50 or 100 μm, depending on the desired pixel dimensions. The scanning provides the y coordinate while the x coordinate for each photon is calculated from the charge collected on the anode strips of the GMD via the centroid equation,

$$x = \sum_i x_i Q_i / \sum_i Q_i \qquad (2)$$

where x_i is the position of the ith anode strip and Q_i is the charge collected by the strip. The calculated x values are then binned into 50 or 100 μm wide pixels. This method of sampling the deposited charge cloud and calculating its centroid leads to a spatial measurement accuracy which is better than the anode spacing of the GMD.

The spatial resolution for photons is determined by the range of the electrons produced by x-ray interactions in the gas. The electron ranges can be kept short and the quantum efficiency of the detector kept high by using a gas mixture based on xenon (Z=54) at high pressure.

For our experiments, we use a gold-on-glass print with 200 μm anode-to-anode pitch, 15 μm wide anode strips, and 90 μm wide cathode strips. There is a drift electrode held 4 mm from the print, which causes electrons to drift towards the print. Typically, the anodes are held at 0 V, the cathodes at -400 to -600 V and the drift plane at -500 to -2500 V. Individual anode pulse height information can be read out through fast charge amplifiers for 16 central anode strips. This provides a 3.2 mm wide area for x-ray imaging. The associated cathodes are grouped together and provide a total energy signal as well as a data acquisition trigger. These seventeen signals, after gating and further amplification, are read through ADCs into a computer. Image analysis is done off-line.

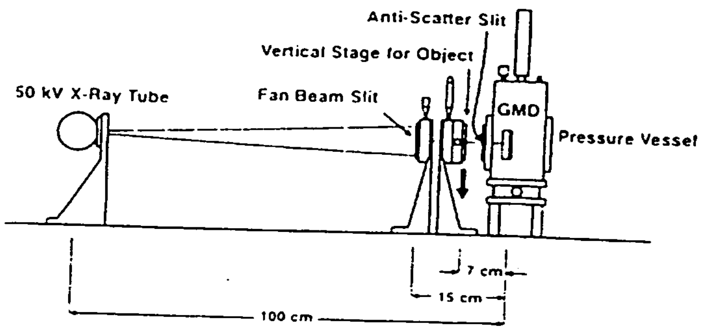

Fig. 2: Prototype Scanned Projection Radiography System

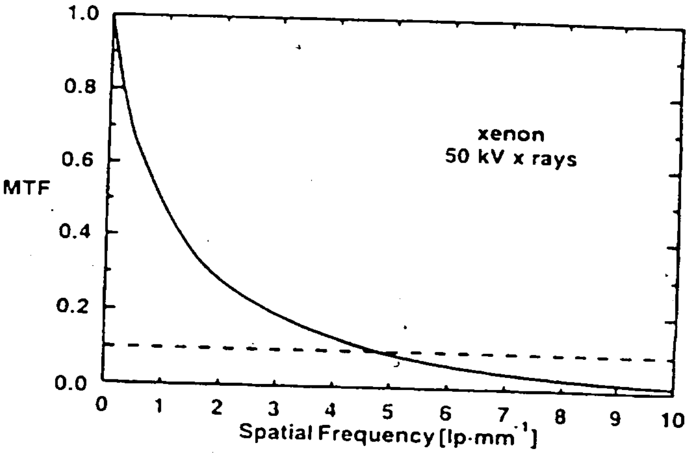

Fig. 3: The modulation transfer function of the imaging system. The GMD was filled with xenon gas mixture at 1 atmosphere.

The modulation transfer function (MTF) of the imaging system was obtained from the measured line spread function of a 38 μm wide slit. High resolution test patterns were also imaged. The energy resolution of the detector was measured with an ^{241}Am source (14, 18 and 60 keV x and γ rays). The spectroscopy measurements were done with an Ortec 142PC/450 preamplifier/spectroscopy amplifier combination and an Ortec 916 multi-channel analyzer.

B. *Results and Discussion*

Using xenon at 1 atm absolute as the fill gas, line-pair test images have demonstrated a limiting resolution of > 4 lp·mm^{-1} (125 μm) for 50 kVp x rays from a tungsten

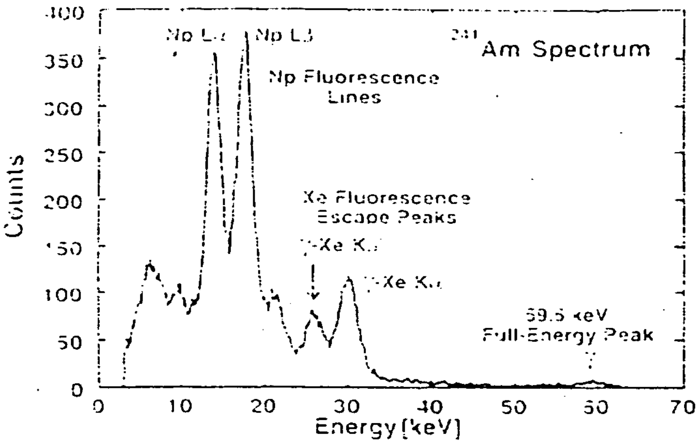

Fig. 4. ^{241}Am γ and x-ray spectrum acquired with xenon gas mixture filled GMD. The escape of xenon Kα and Kβ fluorescence radiation following interactions of 59.5 keV photons produces the two additional peaks at 26 and 30 keV.

anode x-ray tube with 2.4 mm Al filtration. The full MTF curve, calculated from the response of the system to a slit, is given in Fig. 3.

The energy resolution (FWHM) of the GMD was measured to be 10.9 % at 17.7 keV and 5.2 % at 59.5 keV (Fig. 4). These measurements suggest that a GMD based x-ray imaging system has excellent potential for energy discrimination.

Fig. 5 shows images of a microchip in a plastic case taken with 50 kVp x rays. The microchip itself is seated on a metal plate which forms the dark square in the centre. The image on the right has been enhanced by applying an energy discrimination threshold; it is formed from the 60 % of the x rays which deposited less than approximately 15 keV in the detector. The result is a higher-resolution image at the cost of photon statistics.

The GMD is capable of high resolution imaging when filled with a xenon gas mixture at 1 atmosphere. For our present geometry, the quantum efficiency at 1 atmosphere is less than 9% for all energies above 18 keV. Increasing the gas thickness and the pressure will improve the quantum efficiency as well as the spatial resolution.

A GMD SPR system provides excellent scatter rejection but is slower than full field radiography methods. With its good energy resolution, a GMD imaging system could be used for single exposure dual energy radiography. We have previously demonstrated the x-ray imaging capabilities at 8 keV of a GMD system filled with argon/isobutane 90/10 gas mixture at 1 and 2 atmospheres [3] [4].

A Russian group [5] has used a counting SPR system based on a multiwire proportional chamber (1.2 mm anode wire spacing) to obtain chest and pelvic x-ray images.

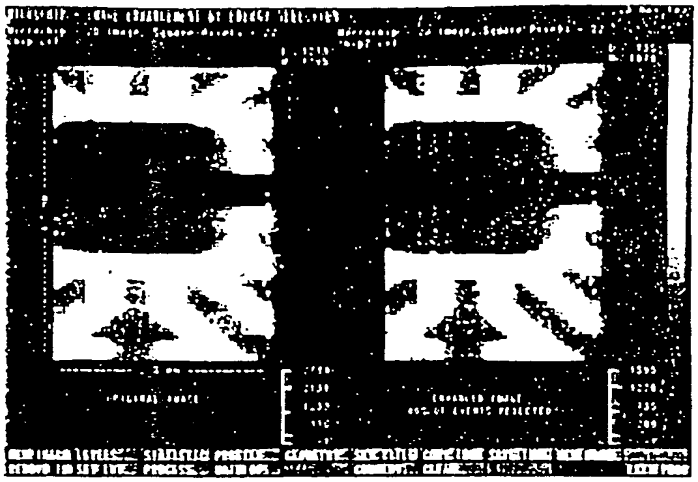

Fig. 5. The images of a microchip (pixel size 50 μm) in a plastic case taken with 50 kVp x rays. The dark area in the images are metal and the light areas are the plastic pin-case. In the image on the left, the resolution in the horizontal plane is degraded due to the long range of ~20 keV photoelectrons. In the image on the right, energy selection has been used to improve the horizontal resolution. Vertical resolution is determined by scanning and is the same for both images.

III. DOSIMETRY

The operating characteristics of the GMD as a dosimeter were studied for various mixtures of tissue equivalent (TE) gas (50% propane, 45% CO_2 and 5% N_2) and Ar at a pressure of 1 atmosphere. For these measurements, all anodes were coupled to a single Ortec 142PC charge sensitive preamplifier. Fig. 6 demonstrates the gain/cathode voltage characteristics of the GMD filled with different ratios of TE gas and Ar. The gain was obtained by looking at the full energy peak of the 5.9 keV x ray from ^{55}Fe.

The ability of the detector to discriminate between radiation types in mixed fields was investigated by measuring the pulse height spectrum for the response of the detector to ^{60}Co and ^{252}Cf neutrons free in air for a group of 8 anodes. A 200 μm pitch GMD filled with 76% TE gas and 24% Ar was exposed to a ^{252}Cf neutron source and a ^{60}Co gamma ray source. The ^{252}Cf source also emits gamma rays such that the GMD is tested in a mixed γ-neutron environment. The eight anodes were coupled to a single amplifying channel (Ortec 142PC) such that a measure of the energy imparted, ε, to a volume of gas of 1.6 x 4.4 x 50 mm was measured for each event. Interesting features of a pulse height spectrum can be enhanced by binning the events in logarithmic bin widths of increasing size and then multiplying each pulse height by the number of counts. Thus, one gets the contribution of events of different ε to the total energy deposited in the gas volume, as shown in Fig. 7. In the case of ^{252}Cf, one observes low-ε events due to Compton electrons from the incident γ

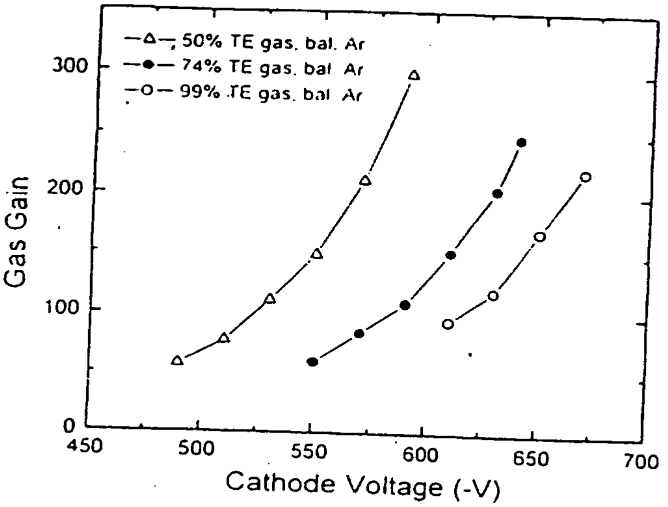

Fig. 6: GMD gas gain as a function of $V_{cathode}$ for different mixtures of tissue equivalent gas (TE) and Ar. In all cases V_{drift} is -1200 V.

rays, while larger size events are due to recoil protons set in motion by the incident neutrons. When ^{60}Co is used, one only observes the small event sizes due to Compton electrons from the γ rays.

The dose to the gas may be estimated by summing all the points of the distribution shown in Fig. 7 and dividing by the mass of the gas probed by all 8 anodes. The event size distribution allows the identification of the various components contributing to the dose and, using an analysis procedure from microdosimetry may lead to the estimation of the radiation quality factors for different radiation types.

IV. FUTURE WORK

The pressure of the xenon in the detector will be increased to 6 atm in order to obtain high quantum efficiency as well as improved spatial resolution. In order to maintain high proportional gain at this pressure, the width of the anode strips will be reduced from 12 μm to 6 μm.

Some preliminary dual-energy imaging investigations will be carried out to demonstrate the capabilities of the GMD for this application. Counting-rate tests are also planned to determine the lower bound on the image acquisition time of the GMD-SPR system.

Preliminary work with dosimetric gases indicate that the GMD has potential for mixed radiation field dosimetry. We are currently investigating the use of the multi channel structure of the GMD for microdosimetry and we will implement design changes to improve the tissue equivalence of the detector. Work in this field is ongoing.

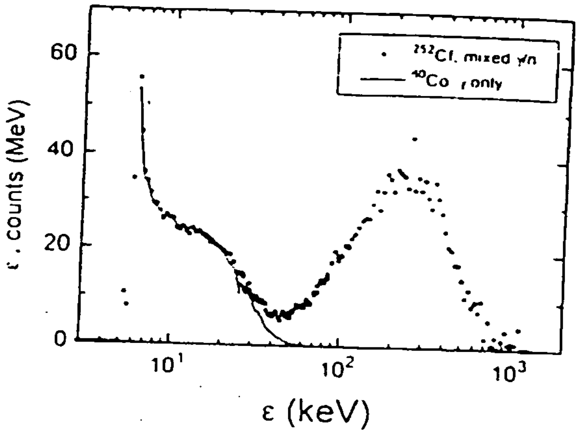

Fig. 7: The contributions to the deposited energy in the TE(76%)/Ar gas at 1 atmosphere as a function of the imparted energy ϵ, are shown for a mixed γ and neutron field from ^{252}Cf and for ^{60}Co γ rays only. The ^{60}Co spectrum has been normalized with respect to the ^{252}Cf spectrum which has 10^5 counts.

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